Atomic Energy Control Board
P.O. Box 1046
Ottawa, Canada
K1P 5S9

Commission de contrôle de l'énergie atomique
C.P. 1046
Ottawa, Canada
K1P 5S9

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# EXPERT SYSTEMS AS DECISION TOOLS

by

Atlantic Nuclear Services Ltd.

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## ABSTRACT

The feasibility of using expert systems as an aid in regulatory compliance functions has been investigated. A literature review was carried out to identify applications of expert systems to regulatory affairs. A bibliography of the small literature on such applications was prepared. A prototype system, ARIES, was developed to demonstrate the use of an expert system as an aid to a Project Officer in assuring compliance with licence requirements. The system runs on a personal computer with a graphical interface. Extensive use is made of hypertext to link interrelated rules and requirements as well as to provide an explanation facility. Based on the performance of ARIES the development of a field version is recommended.

## RÉSUMÉ

Le présent rapport étudie la possibilité d'utiliser des systèmes experts comme appui aux fonctions de conformité réglementaire. Les auteurs ont examiné la documentation existante pour déterminer les applications des systèmes experts aux questions de réglementation. Un système protoype, ARIES, a été mis au point pour démontrer la pertinence d'un système expert comme outil possible des chargés de projet pour s'assurer de la conformité aux conditions des permis. Le système fonctionne à partir d'un ordinateur personnel à interface graphique et fait grand usage d'hypertexte pour joindre les règles et les exigences interreliées, et pour servir d'installation d'explication. D'après le rendement positif d'ARIES, le rapport recommande la mise au point d'un modèle sur le terrain.


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## PROJECT TEAM

This study was carried out by Atlantic Nuclear Services Ltd. with expert input from the School of Computer Science, University of New Brunswick. The Principal Investigators for the project are:

C.K. Scott
Atlantic Nuclear Services Ltd.

B.G. Nickerson and K. Ward
University of New Brunswick

The Atomic Energy Control Board, under the direction of the Scientific Authority Dr. D.J. Martin, provided valuable input and guidance. In particular, Colin Downie's expertise is included in the knowledge base for shutdown depth.

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## 1.0 Introduction

The reactor licensing requirements for CANDU nuclear power plants are based on specific documented rules and requirements and their interpretation in the process of licensing specific plants. The interpretations or precedents are not formally documented, but are part of the 'culture' of the safety and licensing community.

We have undertaken a project to investigate the feasibility of using expert system technology to integrate the diverse licensing rules and requirements. The resulting knowledge base would be used as an aid in supporting the regulatory decision making process.

A literature review was done to determine if expert system techniques are being applied to regulatory functions. The results of the survey are reported in Section 2.0 as a bibliography and other notes.

The adequacy of shutdown depth was selected as the licensing area to be investigated for application of expert system techniques. The scope and types of rules and requirements that apply to an assessment of shutdown performance are outlined in Section 3.0.

A prototype system, ARIES (AECB Regulatory Information Expert System), is described in Section 4. ARIES was developed to demonstrate a system being used to assist a Project Officer in performing his compliance functions. It was developed using the expert system shell, KnowledgePro, which is a personal computer based system. It has a graphical interface, rule and frame representations, and a hypertext facility. All of the features have been used in the prototype system.

The study is concluded with recommendations for further development work to produce a functional decision aid.

## 2.0 LITERATURE REVIEW

A literature review was undertaken to identify work that has already been done in applying expert systems in the area of regulatory compliance. The primary search was with the CAN/OLE system of the Canadian Institute for Scientific and Technical Information. This abstract search was supplemented by discussions with members of the Artificial Intelligence industry and regulators.

### 2.1 CAN/OLE Search

Seven of the CAN/OLE databases were searched with the following literature coverage.

(i) Engineering Index

The EI database, produced by Engineering Information Inc., covers all aspects of engineering and related technology areas. More than

4,500 primary international publications are covered from 1970 to date. Subject areas relevant to the current project include:

- Computers
- Information technology
- Law and government regulations
- Nuclear technology

(ii) INSPEC

Information Services in Physics, Electronics and Computing (INSPEC) is produced by the Information Services Division of the Institution of Electrical Engineers (UK) and provides worldwide coverage on all aspects of physics, electrical engineering, electronics, computers, control engineering and information technology. The database covers journals, conference proceedings, monographs, theses, technical reports, and patents (1970-76). From 1970 to date. Subject areas relevant to the current project include:

- Computer applications
- Computer hardware/software
- Power systems

(iii) National Technical Information Service

The NTIS database, produced by the National Technical Information Service of the United States Department of Commerce, is a multidisciplinary database representing US government sponsored research, development, engineering reports and machine processable data files and related software. The reports originate from over 300 US government departments and agencies, including NASA, Dept. of Defense, Dept. of Energy, Dept. of Health Education and Welfare, the Environmental Protection Agency and the Dept. of Agriculture. The database covers US government reports, government sponsored translations, foreign language reports and US government owned patents from 1964 to date. Subject areas relevant to the current project include:

- Energy
- Engineering
- Environmental pollution and control
- Nuclear science and technology

(iv) NRC Publications

The NRCPUBS database, produced by the Information Exchange Centre of CISTI, provides access to numbered publications written by National Research Council Staff or for the NRC. It covers periodicals, technical reports, conference papers and monographs from 1918 to date.

(v) Electric Power Databases

The EPD database, produced by the Technical Information Centre of the Electric Power Research Institute, contains summaries of research and development projects of interest to the electric power industry in Canada and the United States. Ongoing and completed research projects in both the public and private sectors are covered from 1972 to date.

(vi) Directory of Federally Supported Research in Universities

The IEC database, produced by the Information Exchange Centre of CISTI, contains information on university based research projects funded by Canadian federal government departments; including those contracts awarded by Supply and Services on behalf of other departments. Projects are covered from the fiscal year 1971/72 to date. Subject area relevant to the current project include:

- Computer science
- Energy
- Engineering
- Law

(vii) International Nuclear Information System

The INIS database, produced by the International Atomic Energy Agency, provides worldwide coverage of all aspects of nuclear science and technology used for peaceful purposes. INIS covers approximately ninety-five percent of the world's literature in the field. It covers journals, theses, conference proceedings, books, reports and patents from 1970 to date. Subject areas relevant to the current project include:

- Engineering and technology
- Environmental science
- Legal aspects
- Mathematics and computers
- Nuclear reactors
- Safeguards
- Waste management

Two search strategies were used for keywords as follows:

Strategy 1

(a): expert AND system
(b): regul* AND applications
(c): (a) AND (b)

Strategy 2

(a): expert AND system
(b): regul*
(c): (a) AND (b)
(d): (a) AND applications
(e): (c) AND applications

Search strategy 1) was not successful in producing relevant citations. Therefore, a second strategy was initiated which separated "regulatory" and "applications" and proved more successful. The majority of citations, however, were uncovered during the search of expert systems and applications.

INIS produces twelve listings for expert systems applications. The majority of these papers, however, described expert systems used as expert tools in decision making applications. None of the applications were of a pure regulatory nature. Some examples include, "Expert System Technology for Control Integration in Nuclear Reactors", and "Development of a Microcomputer-Based Nuclear Power Plant Maintenance Expert System".

NTIS produced 68 citations for expert systems applications and there were 209 and 47 from the EI and INSPEC databases, respectively. A similar search of EPD uncovered one paper titled, "Development of an Expert System for Residential Solar and Energy Management Applications". This paper describes an expert system under development which will assist energy auditors in providing expertise to customers on solar and energy management applications.

The following nine publications from the CAN/OLE search are somewhat related to the application of expert systems in a regulatory context.

1. Situation-Assessment and Decision-Aid Production-Rule Analysis System for Nuclear Plant Monitoring and Emergency Preparedness

Gvillo, D.; Ragheb, M.; Swartz, S.

P. 347-354. Applications of Artificial Intelligence V. Bellingham, WA (USA). Society of Photo-Optical Instrumentation Engineers, 1987.

Abstract: A production-rule analysis system is developed for nuclear plant monitoring. The signals generated by the Zion-1 plant are considered. A situation-assessment and decision-aid capability is provided for monitoring the integrity of the plant radiation, the reactor coolant, the fuel clad, and the containment systems. A total of 41 signals are currently fed as facts to an inference engine functioning in the backward-chaining mode and built along the same structure as the E-Mycin system. The goal-tree constituting the knowledge base was generated using a representation in the form of fault trees deduced from plant procedures information. The system is constructed in support of the data analysis emergency preparedness tasks at the Illinois Radiological Emergency Assessment Centre (READ).

2. Expert System Characteristics and Potential Applications in Safeguards

Chapman, L.D.

Nucl. Mater. Mange. (1986). V. 15 P. 392-396

Abstract: The general growth of expert, knowledge-based (KB) or rule based systems will significantly increase in the next three to five years. Improvements in computer hardware (speed, reduced size, power) and software (rule based, data base, user interfaces) in recent years are providing the foundations for the growth of expert systems. A byproduct of this growth will undoubtedly be the application of expert systems to various safeguards problems. Characteristics of these expert systems will involve 1) multiple rules governing an outcome, 2) confidence factors on individual variables and rule sets, 3) priority, cost, and risk based rule sets, and 4) the reasoning behind the advice or decision given by the expert system. This paper presents characteristics, structures, and examples of simple rule based systems. Potential application areas for these expert systems may include training, operations management, designs, evaluations, and specific hardware operation.

3. Expert Systems and Emergency Management: An Annotated Bibliography

Gass, S.I.; Bhasker, S.; Chapman, R.E.

Nov 86; 181P; Final Rept; Library of Congress Catalog Card No. 86-600591. Sponsored by Federal Emergency Management Agency, Washington, DC; PC A09/MF A01

Abstract: This report is the result of an in-depth review of the recent technical literature on expert systems. The material contained in the report provided a basis for assessing the potential for using expert systems in emergency management operations. In choosing the material for inclusion in the report, special emphasis was placed on those aspects of expert systems which addressed the types of problems encountered in emergency management operations. The report is designed for use as a resource document and as a tutorial on expert systems and emergency management. Each chapter consists of a brief topic essay followed by a set of references which expand on the main themes of the essay.

4. Landfill Site Selection: A Microcomputer Expert System

Rouhani, Shahrokh; Kangari, Roozbeh

Microcomput Civ Eng V 2 N 1 Mar 1987 P 47-53; 6 Refs.

Abstract: Sanitary landfills are common facilities for waste disposal. The process of designating a location as a landfill requires extensive studies of biogeochemical and hydrologic characteristics of all potential sites. This process demands a considerable amount of empirical inputs, expert opinions, and heuristic rules. A site selection process can be modeled only by incorporating the available empirical and expert rules into our decision making process. This task can be accomplished in the framework of knowledge-based expert systems. A prototype expert system for site selection is presented. The rules are based on U.S. EPA documents for ranking of uncontrolled hazardous waste sites for remedial actions. They include rules concerning ground water routes, local climate, water characteristics, planned features of the proposed landfill facility, and targets at risk. The above model is programmed with the aid of Insight 2 +, which is a microcomputer shell program.

5. GEOTOX: A Knowledge-Based System for Hazardous Site Evaluation

Wilson, J.L.; Mikroudis, G.K.; Fang, H.Y.

Int J ARtif Intell Eng V 2 N 1 Jan 1987 P 23-32; 14 Refs.

Abstract: GEOTOX, an expert knowledge-based system, is a new tool for computer-assisted 'expert' consultation in evaluating waste disposal sites and improving prioritization of appropriate remedial measures to cost-effectively reduce further risk. After describing the important characteristics of the problem domain and discussing various site evaluation methods, this paper directs attention to the knowledge representation scheme in GEOTOX with emphasis on a case-study. This paper illustrates how artificial intelligence techniques can provide assistance to engineers facing an important problem - the assessment of waste disposal sites.

6. PROLOG-Based Expert System for Encoding Seismic Design Provisions

Alim, Seema

Natl Engineering Services (Pakistan) Ltd, Karachi, Pak., Civ Eng Syst V 4 N 1 Mar 1987 P 39-44; 19 Refs.

Abstract: Provisions from the tentative seismic design code prepared by the Applied Technology Council (ATC3-06) have been selected here for demonstrating how a code of practice can be documented as a PROLOG-based expert system. The significant feature of this expert system is that it has been encoded in a logic programming language, PROLOG (a fifth generation computer programming language). The expert system described in this paper can be considered as a guide to the use of the ATC3-06 provisions and does not cover all the details of the tentative code. The expert system helps the user to establish the design parameters necessary for seismic design in accordance with these provisions. It then uses this interactively-gained information to make recommendations about the appropriate seismic design method to the user. In the future, this expert system is to be interfaced with a seismic design package in order to integrate seismic analysis with design decision-making.

7. EVAL - An Expert System for Evaluating Written Reports

Marshall, Stewart

Int J Electr Eng Educ V 24 N 1 Jan 1987 P 23-31; 4 Refs.

Abstract: As an assignment for the course 'Verbal Communication', undergraduates in their fourth year of an electrical engineering degree were asked to write reports evaluating three microcomputers. What was unusual for this particular class was that their 'microcomputer evaluation reports' were evaluated by a microcomputer. This article describes a simple 'expert system' which assists the tutor in the evaluation of written reports.

8. Implementation of a Knowledge Based Seismic Risk Evaluation System on Microcomputers

Miyasato, Glenn H.; Dong, Weimim; Levitt, Raymond E.; Boissonnade, Auguste C.

Int J Artif Intell Eng V 1 N 1 Jul 1986 P 29-35; 5 Refs.

Abstract: This article reports on the use of an expert system to determine the level of risk a building may face due to seismic hazard. The risk level is dependent on the building use, design, construction, and the ground motion level to which the building may be exposed. Theories about the many factors involved in a seismic risk evaluation are not well defined. Measurements are difficult to verify. However, seismic risk experts do have judgemental and heuristic rules based upon such experience, a set of rules was developed and implemented on DECIDING FACTOR, a microcomputer program for developing expert

systems. An internal validation performed over several buildings showed that the system evaluation corresponded favourably with the expert's opinion. When further validated and refined, this seismic risk evaluation system could be used to aid in city planning, insurance assessment, and disaster mitigation.

9. The Applications of Artificial Intelligence to Law: A Survey of Six Current Projects

Cook, S.; Hafner, C.D.; Thorne, McCarty, L.; Meldman, J.A.; Peterson, M.; Sprowl, J.A.; Sridharan, N.S.; Waterman, D.A.

AFIPS Conference Proceedings. Vol. 50. 1981 National Computer Conference

Abstract: The literature on computer-based consultation systems has often suggested the possibility of building an expert system in the field of law, but it is only recently that several researchers have begun to explore this possibility seriously. For this session, the authors have assembled summaries of six major projects on the applications of artificial intelligence to legal problem domains, and they have invited representatives of these six projects to participate in a panel discussion of their work.

## 2.2 AI Literature

Current AI literature that was available at UNB libraries was reviewed for expert system applications. B.G. Buchanan [Ref.1] has published an excellent review. His review contains a bibliography of 363 papers, articles, and reports. None of the titles indicate any applications to regulatory functions. Buchanan lists 61 expert systems that have passed from the development stage to testing or in-service use by 1986. None of the systems he described are applications to a regulatory function.

## 2.3 Nuclear Industry

There are no reported applications of expert systems to assist the nuclear regulatory process in Canada. The US Nuclear Regulatory Commission was contacted and in telephone conversations the following was determined:

- The USNRC has not applied expert systems to the regulatory process.
- The USNRC has no regulatory requirements for the use of expert systems.
- Research programs are being established to investigate the use of expert systems.

- An expert system is being developed for application in an Emergency Response Centre.

- The Electric Power Research Institute is developing several expert systems in non-safety areas.

## 2.4 Other Industries

In a survey of expert system shells, Information Builder's, Inc. reported that their system, Level5 has been applied in the mining industry. In particular, a system had been developed for demonstrating compliance with federal (US) mining regulations. Unfortunately, in telephone conversations the company said there is no published description of the system.

## 3.0 Reactor Licensing Requirements

The reactor licensing area associated with the demonstration of an adequate shutdown depth was selected for constructing a prototype expert system. Further, two users of the expert system are identified:

User 1 - An AECB Project Officer stationed at a nuclear generating station and auditing the operation of the station for compliance with the Reactor Operating License.

User 2 - An AECB staff safety expert who would develop and maintain the expert system for the Project Officers. Once coded he would also use the knowledge base for reference purposes in safety evaluations.

The staff Safety Analyst now serves as a resource person for the Project Officer. The expert system would 'transfer' to the Project Officer much of the Safety Analalyst's expertise. This will aid the Project Officer in his decision making process and relieve the Safety Analyst from routine consultations.

The Project Officer is routinely confronted with situations where there is a change in equipment status or operating procedure. He must then address the following:

1) What is the safety significance of the change?

2) Is the plant still within the licensed operating envelope?

3) If the plant is outside the allowed envelope, is it possible to make an exception under certain conditions?

4) What direction, if any, must be given to the plant Operations Staff.

Figure 1 illustrates the different areas of the regulatory/licensing review and audit process that support the operating envelope as defined in the Reactor Operating License.

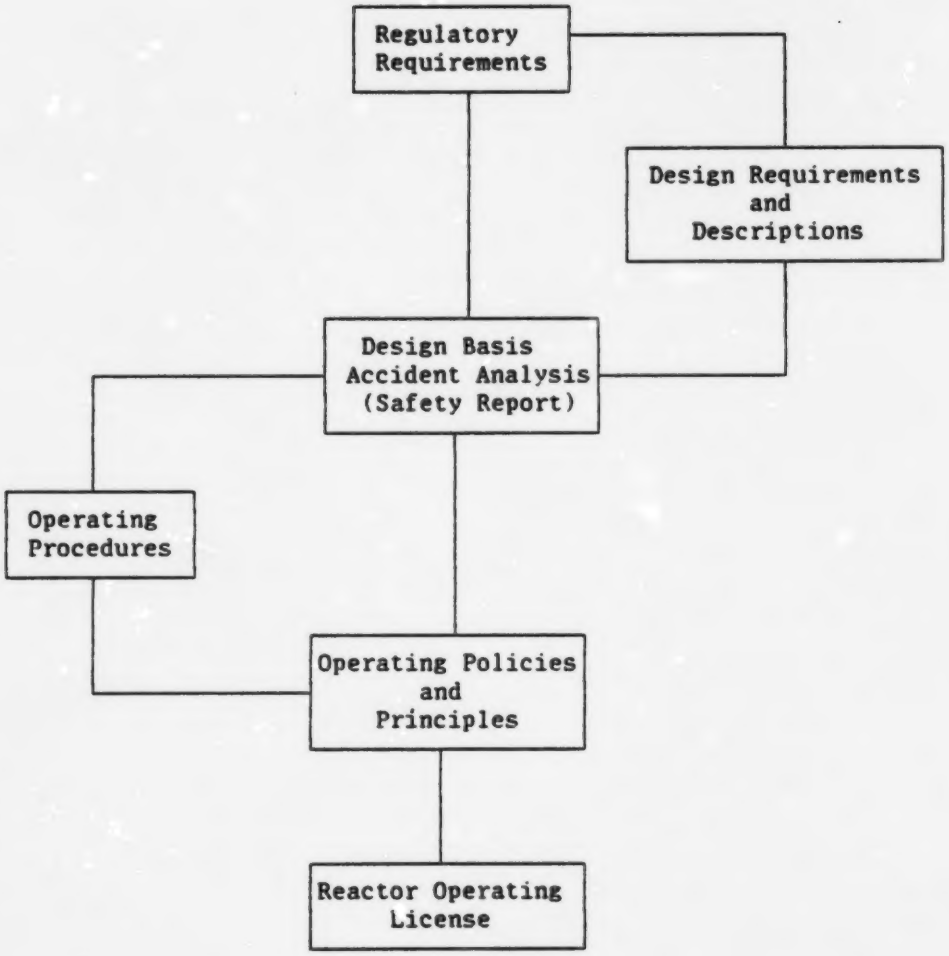


Figure 1 - Licensing Requirements, Analysis and Procedures Supporting a Reactor Operating License.

## 3.1 The Knowledge Base

The knowledge base for the expert system consists of facts and rules associated with the performance of the shutdown systems and the adequacy of shutdown depth. The 'facts-base' consists of all equipment and plant information necessary for applying the regulatory requirements. It includes among other things:

- configuration of all the reactivity devices
- reactor power level
- reactor power history
- moderator poison concentration
- primary coolant temperature
- $D_2O$ purity of the heat transport system

The 'rule-base' consists of all regulatory requirements that are relevant to the demonstration of shutdown system performance. These rules are given in Regulatory Documents and by precedent from past licensing actions. The result is a complex set of rules and interrelated safety issues. Examples of rules are the following:

1) Performance [Ref.2]

Minimum allowable performance standards shall be defined for each shutdown system and shall be listed or referenced in the Safety Report. The minimum allowable performance standards shall also be specified for all major equipment necessary for correct operation of each shutdown system.

Note:

The performance requirements of a shutdown system refer only to its role in shutting the reactor down. For those requirements for which fuel cooling or containment are also necessary, credit for these functions may be taken in demonstrating that such requirements are met, in accordance with the terms of reference 1.

For events specified in reference 1 requiring prompt shutdown action, each shutdown system shall be designed such that, acting alone, it can ensure that:

i) the reactor is rendered subcritical and maintained subcritical;

ii) the relevant dose limits specified in reference 1 are not exceeded;

iii) loss of primary heat transport system integrity shall not result from any fuel failure mechanism.

2) Environmental [Ref.2]

Each shutdown system shall be designed such that, for all relevant class 1, 2, 3, and 4 events specified in Table 1 of reference 1, dynamic effects or jet forces caused by the event cannot result in impairment of the shutdown system to an extent that relevant requirements in section 2.3.1 would not be met.

For all relevant class 5 events in Table 1 of reference 1, at least one shutdown system shall be designed such that dynamic effects or jet forces caused by the event cannot result in impairment of that shutdown system to an extent that the relevant requirements in section 2.3.1 would not be met.

3) Separation and Independence [Ref.2]

The shutdown systems shall be of diverse designs and shall be physically and operationally independent from each other, from process systems and from other special safety systems.

The effectiveness of a shutdown system in shutting the reactor down in accordance with section 2.2 shall not be dependent on the correct functioning of a process system or other special safety system.

The design shall be such that normal functioning of process systems cannot reduce the effectiveness of a shutdown system such that the requirements of section 2.2 would not be met.

4) Safety Analysis Assumptions [Ref.3]

The values of input parameters used in the analysis of each event shall ensure that the predictions of consequences is conservative and applicable at all times by taking account of:

(a) the different plant states for which continued operation will be permitted by the operating procedures;

(b) the uncertainties associated with each parameter.

Mathematical models and associated calculational methods used shall satisfy the following requirements:

(a) conservative prediction is obtained;

(b) all important physical phenomena shall be represented;

(c) simplifications shall be justified as being appropriate and conservative;

(d) adequate numerical accuracy shall be demonstrated;

(e) as far as practible mathematical modes shall be verified by operating experience or experimental evidence;

(f) changes, arising from the event, in the effectiveness of processes shall be accounted for. These shall include but not be limited to:

(i) adverse environmental conditions such as steam, dousing, flooding and radiation.

(ii) changes in support system performance e.g. electrical power, cooling water and instrument air supplies.

5) Design Basis Accident Analysis [Ref.3]

An assessment of shutdown depth includes the following accident scenarios:

Class 2

(i) Pressure tube/calandria tube failure

(ii) Flow blockage in any single reactor fuel channel assembly.

Class 5

Combine the Class 2 events with each of the following in turn:

- failure of emergency coolant injection
- failure to close of the isolation devices on the interconnects between the reactor main coolant loops
- failure of rapid cooldown of the steam generators
- one door open of the airlock or transfer chamber most critical for radioactive releases from containment and the seals on the second door deflated.

6) Operational Policies and Principles

The following Operational Policies and Principles are typical of a CANDU station and relevant to shutdown system performance.

(i) In the event that a shutdown system operates, it shall be returned to the poised state as soon as practible without causing criticality, or the reactor shall be placed in an approved guaranteed shutdown state.

(ii) The rate of fuelling shall be limited such that the concentration of boron in the moderator is restricted to the equivalent of 5 mk excess reactivity.

(iii) The void coefficient (void reactivity) shall not be modified by adding poison to the primary coolant without the authorization of the Station Manager. The isotopic concentration of the coolant shall at all times exceed 97.43 percent $D_2O$ by mass when the reactor is in operation (97.15 atom percent).

(iv) A shutdown system shall only be considered available if, on demand, it is capable of inserting negative reactivity at the rate and to the depth assumed in safety analysis documented in current licensing submissions and if it would be capable thereafter of maintaining an adequate shutdown margin.

For SDS1, compliance with the previous paragraph is not assured if less than 26 shutoff rods are poised and available, regardless of the position of the other rods.

For SDS2, compliance with the previous paragraph is not assured if more than one poison tank is isolated, or if the helium storage tank pressure is less than 7.88 MPa(g), or if the poison concentration in more than one tank is less than 8000 ppm of Gadolinium.

(v) If a shutdown system becomes unavailable, the reactor shall be shut down in an orderly manner within 30 minutes, and the primary circuit then cooled to below 100°C. The reactor shall then be placed in a Guaranteed Shutdown State unless the fault can be corrected within 8 hours of its discovery during a period in which the reactor is certain to have poisoned out.

7) <u>Reactor Operating License</u>

The following license requirements are typical for a CANDU Station and restrict operation to approved states.

(i) Except with prior written approval of the Board no change which would render inaccurate the description or analyses in the Safety Report of documents listed in the

application shall be made to the reactor Shutdown System No. 1, Shutdown System No. 2, containment system, emergency core cooling system or associated systems necessary for the proper operation of theses systems.

(ii) Except with prior written approval of the Board, no change shall be made in any equipment or procedure that involves possible hazards different in nature or greater in magnitude or probability than those stated or implied in the Safety Report or documents listed in the application.

The knowledge base and all the facts and rules implemented in the prototype expert system is given in the source code [Ref.4].

## 4.0 Prototype Expert System

The expert system shell, KnowledgePro was selected for developing the prototype system. It has the following desirable features:

1) PC based system and inexpensive

2) Rule-based and Frame-based representation

3) Hypertext knowledge base

4) Graphics interface

The other low cost development shells for personal computers do not offer as complete a set of features. We judge the frame, hypertext and graphic representations to be necessary for an effective regulatory knowledge base system.

### 4.1 ARIES

AECB Regulatory Information Expert System (ARIES) is a demonstration application. It is designed to test the feasibility of a "regulatory expert system". ARIES provides not only a program for storing and accessing AECB regulatory documents, but it also "applies" these regulations to an analysis of the safety of nuclear power plant operating conditions. It is an automated decision tool to assist AECB staff who must be familiar with the many regulations and requirements governing plant operations and who must understand the complex relations between operating conditions and plant safety.

Specifically, ARIES is a decision tool to assist AECB Project Officers who assess the safety of nuclear generating station operations. It would be used when the Project Officer analyzes proposed changes to operating conditions/procedures and decides whether such changes represent a safe state. To assist these decisions, ARIES must incorporate both an "understanding" of AECB requirements and a "knowledge" of plant processes and systems. These facilities are built into the "knowledge-based" or expert system approach used in ARIES.

The demonstration version of ARIES is not a complete representation of AECB regulations or AECB regulatory decision-making. Rather, it recognizes only two of the many possible decision scenarios. The two scenarios represent different operating conditions where the Project Officer is required to assess plant safety. The scenarios are described by the systems which are affected and the events which impinge on these system"

Scenario 1: Reactor Regulating System.

A review of the Shift Log reveals that an adjustor rod is stuck half way out of the core. The Project Officer must decide

--- whether this fault has any safety significance,
--- if yes, then why is it significant, and
--- what is the limiting safety issue.

Scenario 2: HTS Loop Isolation Valve Logic.

A loop isolation valve is failed open. The Project Officer must decide

--- whether the loop isolation system is impaired,
--- what actions are required by the operating staff,
--- what is the safety significance.

The demonstration version of ARIES includes routines to analyze these two events. The routines are designed to answer the questions posed above, but they are also capable of other decisions which follow from ARIES "knowledge base" about the two systems.

4.1.1 Scenario 1

ARIES analysis of the RRS fact base provides an assessment of shutdown depth. Shutdown depth is a measure of reactivity that is based on the current state (i.e., power level, fuel status and effective FP days). It also depends on the configuration of mechanical reactivity devices, including adjusters, MCAs and LZCs.

ARIES knowledge base includes a set of rules which, for each reactor state, specifies a reactivity amount. For example, ARIES rules return different values for the following test data:

1. Equilibrium Fuel, Power Level is > 60% FP, Coolant Temperature >= 100 degrees (Hot) and Effective FP Days > 5.

2. Equilibrium Fuel, 0 - 100% FP, Hot, Effective FP Days < 5.

3. Equilibrium Fuel, 0% FP, Coolant Temperature is < 100 degrees (Cold) and any Effective FP Days.

4. Fresh Fuel, 0% FP, Cold and any Effective FP Days.

Another set of rules returns a reactivity amount for each configuration of each reactivity device.

Using these values, ARIES estimates the reactor's shutdown depth, then determines whether this depth is sufficient for continued operation.

RRS analysis also tests the availability of shutdown systems SDS1 and SDS2. Specifically, it recognizes when SDS1 and SDS2 configurations are inconsistent with Operating Policies and Principles (OPP).

5. The number of available shuttoff rods (SDS1) is less than 26.

6. The number of available poison tanks (SDS2) is less than 5.

RRS rules also check for other contradictions between RRS facts and the OPP. That is, ARIES reports an action for the following data:

7. The concentration of moderator Boron exceeds 10 ppm.

8. Banks of adjusters are withdrawn out of sequence.

9. For a bank of adjusters, a rod is stuck in.

4.1.2 Scenario 2

ARIES knowledge base for Loop Isolation analysis tests the availability of loop isolation valves as defined by OPP. Valve availability depends on the status of the paired valve and of other logic devices (e.g. instrument loop, 2/3 logic, test handswitches and valve control handswitches). Since ARIES understands the connections among these devices, there are numerous combinations of data that are inconsistent with the OPP requirement. ARIES' reliability was tested using the following sets of inconsistent data:

1. Instrument loops P201K and P201M are failed.

2. Both ODD and EVEN 2/3 logic devices are failed or unavailable.

3. The EVEN 2/3 logic device is failed or unavailable, and test handswitch 63432-HS115K is set to 'test'.

4. The EVEN 2/3 logic device is failed or unavailable, and valve control handswitch 63331-HS22 is set to 'stop'.

5. Isolation valve 3331-MV22 is failed and open, and test handswitch 63432-HS115M is set to 'test'.

6. One of the above, and HTS coolant temperature is less than 100 degrees C.

ARIES was also tested using the following consistent data:

7. Isolation valve 3331-MV13 is failed and closed, valve 3331-MV22 is failed and open, and valve control handswitch 63331-HS13 is set to 'open'.

8. Instrument loop P201L is failed and test handswitch 63432-HS115K is set to 'test'.

## 5.0 Summary, Conclusions and Recommendations

### 5.1 Summary

A prototype expert system, ARIES, has been developed to demonstrate the use of expert systems as a decision support tool in reactor regulation. ARIES is designed to provide decision support to a Project Officer who is monitoring compliance with the conditions of a Reactor Operating License.

ARIES is consulted as follows:

1) Update the current operating state of the reactor and configuration of equipment and components.

2) Query ARIES as to the safety significance of the proposed operating state and configuration.

3) ARIES returns an assessment of the proposed operating state as being within or outside the licensed operating envelope.

4) ARIES will advise the Project Officer of contraints that must be placed on operation in the proposed configuration.

The prototype version of ARIES allows the user to specify the configuration of reactivity mechanisms or the heat transport loop isolation subsystem. These two cases were selected to demonstrate the implementation of rules concerning the adequacy of shutdown depth. Rules are implemented for the following:

1) calculation of shutdown depth margin given a specific operating state and configuration of the reactivity mechanisms.

2) availability of special safety systems, SDS1, SDS2, and ECC.

3) other operating constraints imposed by safety analysis such as boron concentration in the moderator.

The full set of rules included in ARIES is given in Reference 4.

In addition to the knowledge base of facts and rules, ARIES uses hypertext extensively as an explanation facility. Hypertext is used in two ways:

1) to make the link between interrelated licensing requirements/rules.

2) to elaborate the significance of specific rules or conditions.

ARIES can also be used by the Safety Analyst who is concerned with the evaluation of the margin for shutdown depth. The knowledge base brings together in a coherent fashion the many inter-related aspects of reactor regulation that apply to a specific safety issue. It also is a powerful way to access the requirements and regulations that are given in regulatory guides, memos, letters and other documents associated with rule making.

## 5.2 Conclusions

ARIES demonstrates that an expert system can be used as a powerful tool to support the compliance functions of a Project Officer. It is feasible to implement such a system on a desk top personal computer so that it can be accessed directly at a site office.

The complexity of many regulations and their interpretation makes a hypertext facility an essential part of the system.

KnowledgePro has most of the features needed to develop a regulatory system. However, its slowness is barely acceptable for the ARIES prototype and it would be too slow for a working system.

Given the complexity of the coding for ARIES, working expert systems should be developed for specific tasks. For example, an expert system could be developed from the ARIES model to monitor the availability of the special safety systems. This, in turn, could be developed as modules for each of the four systems.

The literature review did not identify any expert systems that have been developed for the nuclear regulatory function. ARIES represents a unique attempt to apply expert systems as a compliance aid.

## 5.3 Recommendations

Given the successful implementation of the ARIES prototype, further development work is to be recommended. In particular, we recommend the following:

1) Focus initially on the Project Officer as a user combined with the associated expert safety analyst as the developer and user as well.

2) Select a specific goal for the expert system aid such as monitoring the availability of the special safety systems. The details of the availability requirements are complex and an ARIES type aid would of great value in assessing compliance.

3) Design the expert system so that it always reflects the current status of the plant. Thus, the Project Officer only enters only changes that occur on a day-to-day basis.

The temporary changes that routinely are made to plant systems (Jumper Record) can and do affect the definition of the allowed operating envelope for the

reactor. It would be desirable and a powerful aid to the Project Officer if the Regulatory Knowledge Base could be linked to the Jumper Record. Therefore, we recommend,

4) Development of a method to update the rule base of the expert system to dynamically reflect temporary changes in plant procedures and systems.

The integrity of an expert system that is used as a decision aid will be essential. Therefore, we recommend,

5) Development of procedures for developing and maintaining a Regulator Knowledge Base so that its integrity is assured.

## 6.0 References

1. B.G. Buchanan, "Expert Systems: Working Systems and the Research Literature", Expert Systems, Vol 3, No.1 pp 32-51, 1986.

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3. Consultative Document C-6, Proposed Regulatory Guide, "Requirements for the Safety Analysis of CANDU Nuclear Power Plants", June 1980.

4. ARIES: AECB Regulatory Information Expert System - User's Guide, B.G. Nickerson, K. Ward and C.K. Scott, February 28,1989.